PATENT SPECIFICATION

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DRAWINGS ATTACHED.

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International Classification:—H 01 b 7/02.

COMPLETE SPECIFICATION.

Electrical Transmission Lines.

We, E.I. Du Pont De Nemours and Company, a corporation organised and existing under the laws of the State of Delaware, United States of America, of Wilmington, State of Delaware, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

Electrical cable is used generally for either communications purposes or for the transmission of power. Communications cable is commonly operated at low voltage but sometimes at high voltage; power cable is operated at high voltage. Such cables are considered generically herein as electrical energy transmission lines.

Electrical energy transmission lines comprise inner conductor(s), dielectric space material, and an outer protective coating. Such outer protective coatings may be either conductive or insulating, electrically.

Such lines comprising conductive outer protective coatings include the following. Power cable generally consists of at least one inner conductor spaced from and enveloped by a coextensive running outer conductor, also called a neutral or ground conductor, or neutral shield. Communications cable likewise generally consists of at least one inner conductor and enveloping coextensive running outer conductor spaced from the inner conductor. Generically, the outer conductor of either the power cable or the communications cable is considered herein as the shield conductor. For either power or communications cable, when the inner conductor and shield conductor are concentric with one another, the inner conductor can be called the central conductor, and the transmission line can be called coaxial cable. It is common, however, for more than one inner conductor to be present within a single shield conductor, with the inner conductors being spaced from each other as well as from the shield conductor. Examples of such energy transmission lines include sector power cables, either belted or shielded, and quaded pair and balanced parallel wire communications cables.

The second type of energy transmission line mentioned above is that in which one or more inner conductors are covered with an outer protective coating which is an insulator (i.e., nonconductor), instead of a shield conductor as discussed above. An example of the second type of line is the balanced twin-lead transmission line, sometimes called parallel two-wire cable, used for communications purposes.

Each of the various types of lines discussed hereinbefore may be combined with lines of the same and/or different type to satisfy the requirements of particular applications.

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In each of the various types of electrical energy transmission lines, whether used individually or in combination, dielectric material is present between the inner conductor and the outer protective coating, the latter being either a shield conductor or an insulator and, when more than one inner conductor is present, between the inner conductors, to space and electrically insulate the conductors from one another.

Two criteria by which such dielectric material is evaluated are dielectric strength, (sometimes called electric strength), and dielectric constant. *Dielectric strength* is a measure of the ability of the dielectric material to withstand electrical stress and is calculated as voltage at breakdown divided by thickness of the dielectric material; dielectric strength determines the maximum operating voltage of the line, which is the maximum voltage at which the line will operate indefinitely long without electrical breakdown. *Dielectric constant* is a measure of the capacitance or energy storage of the dielectric material. The higher the dielectric constant, the greater the energy storage and therefore, the shorter critical length (length over the line will transmit electrical energy) of the line. The importance of these criteria will generally depend on the voltage conditions under which a particular line is used.

Heretofore, the dielectric spacer material in electrical energy transmission lines has been provided in two general ways: (1) as a combination system of a fluid (e.g., air or fluid of higher dielectric strength such as oil or so-called dielectric gas) with a solid structure used to position the conductors mechanically, or (2) as a solid structure by itself.

In the combination fluid-solid system, the fluids, particularly air which is commonly used in communication cable, are susceptible to breakdown under high impulse voltage such as occurs when lightning strikes nearby. The solid structures typically used in the combination system are susceptible to surface tracking (i.e., formation of a conductive path across nonconductive surface) which both lowers the maximum operating voltage of the line and increases its energy loss, the latter effect resulting from electrical discontinuities in the electrical field surrounding the inner conductor.

The solid structure used by itself is generally dielectric polymeric material, which may be either blown or unblown. When blown, the volume of gas present in the cells within the polymeric material is less than that in the combination system discussed above. While the polymeric material is more resistant to electrical breakdown than the fluid-solid combination discussed above, it has a relatively high dielectric constant, thereby decreasing the critical length of the line.

The present invention provides an improved dielectric spacer structure for use in electrical energy transmission lines including, but not limited to, the various cables hereinbefore described. The dielectric spacer structure of this invention comprises a ribbon of dielectric polymeric material, the ribbon having a continuous uniplanar film and a plurality of ribs extending from at least one surface of the film, the bulk density of the ribbon being less than 30% of the density of the polymeric material from which it is formed. The ribbon is employed to wrap inner conductors to separate and electrically insulate the inner conductors from one another when more than one inner conductor is present, and to separate and insulate inner conductor(s) from the outer protective coating (either shield conductor or insulator).

In one embodiment of this invention, the ribbon wrapped around the inner conductor forms a discontinuous layer, while in another embodiment the ribbon forms a continuous layer. A discontinuous layer can be formed by wrapping the ribbon in an open helix around the inner conductor. One form of continuous layer is obtained by wrapping ribbon in the form of a closed helix around the inner conductor. Another form of continuous layer is obtained by wrapping of ribbon in longitudinally-folded or cigarette paper wrap fashion (see Figure 12) around the inner conductor.

The film that is present at all points between the inner conductor and outer coating in the continuous layer embodiment is an effective barrier against breakdown caused by high impulse voltages. The spaces between ribs of the ribbon may be filled with air or a fluid of higher dielectric strength such as gas.

In either the discontinuous layer or the continuous layer embodiments, a plurality of such layers of ribbon can be used. When the ribbon is wrapped helically, the direction of helical wrap in each successive layer can either be reversed from that in the previous layer or be in the same direction as the previous layer. Film is present at all points between the inner conductor and outer coating, when for a plurality of layers of open helical wrapping, the turns of each succeeding layer are offset from the turns of the preceding layer in the same direction, i.e., the turns of one layer straddle the space between the turns of the preceding layer in the same direction, providing at least one rib on each side of the space. The same kind of offsetting can be employed for continuous layers of wrapping. One or more layers of one type of wrapping can be com-

bined with one or more layers of wrapping of another type.

Surprisingly, when a sufficient number of layers of ribbon are present to divide the gap at all points between the inner conductor and outer coating into at least three concentric spaces, corona inception voltage (as hereinafter described) is increased rather than decreased, as would have been expected from experience with single solid surfaces present between such conductors which show a decrease in the corona inception voltage. Thus, the ribbon can be used to increase the maximum operating voltage of a line merely by increasing the number of layers of such ribbon. This surprising result is obtained without sacrifice of dielectric constant.

These and other embodiments of this invention will be described more fully hereinafter with reference to the accompanying drawings, in which:

FIG. 1 is a partially cut-away view of a length of transmission line incorporating features of this invention;

FIG. 2 is an enlarged cross-section taken along line 2—2 of FIG. 1;

FIG. 3 is an enlarged perspective view of part of one layer of closed helical wrapping of this invention;

FIG. 4 shows another embodiment of ribbon for use as helical wrapping in this invention;

FIG. 5 is a partial cross-section of a transmission line in this invention employing one embodiment of closed helical wrapping with the ribbon of FIG. 4;

FIG. 6 is a partial cross-section of a transmission line employing another embodiment of closed helical wrapping with the ribbon of FIG. 4;

FIG. 7 is a perspective view of another embodiment of ribbon for use in the present invention;

FIG. 8 shows in diagrammatic side elevation apparatus for making ribbon for use in the present invention;

FIG. 9 shows in cross-section one embodiment of molding apparatus for use in the apparatus of FIG. 8;

FIG. 10 shows in cross-section another embodiment of apparatus for use in the apparatus of FIG. 8;

FIG. 11 shows an embodiment for laterally confining molten thermoplastic resin in an embodiment of roll pattern for making ribbon useful in the present invention;

FIG. 12 is a partially cut-away view of ribbon being wrapped in cigarette paper wrap fashion about a central conductor;

FIG. 13 is an enlarged cross-section taken along line 13—13 of FIG. 12;

FIG. 14 is a partially cut-away view of another embodiment of transmission line of this invention;

FIG. 15 is a partial cross-section of a transmission line of this invention employing another embodiment of closed helical wrapping with ribbon of the type shown in FIG. 3;

FIG. 16 shows schematically, wrapping an inner conductor with still another embodiment of ribbon;

FIG. 17 shows an end view of the conductor of FIG. 16;

FIG. 18 shows schematically, wrapping an inner conductor with still another embodiment of ribbon;

FIG. 19 shows an end view of the conductor of FIG. 18;

FIG. 20 is a schematic cross-section of a sector cable incorporating features of this invention;

FIG. 21 is a schematic cross-section of an unshielded balanced twin-lead communications line incorporating features of this invention; and

FIG. 22 shows a partially cut-away view of a transmission line formed with wrapped discontinuous layers of ribbon.

In discussing the drawings, for convenience specific reference is made to power cables wherein the outer protective coating is a conductor. These comments are also applicable where the outer protective coating is an insulator.

Referring to the drawings, FIG. 1 shows a transmission line 2 consisting of a shield conductor 4 in the form of a tube and an inner, or in this case, a central conductor 6 having a common axis 8 with that of the shield conductor. The transmission line 2 is thus a coaxial cable. Central conductor 6 is covered with a first layer 10 of helically wrapped ribbon 9. This layer is covered with another layer 12 of the same ribbon helically wrapped in the opposite direction, which is in turn covered by a third layer 14 of the same ribbon helically wrapped in the same direction as the ribbon of layer 10. The third layer 14 is covered by a fourth layer 16 of ribbon 9 helically wrapped in the opposite or reverse direction, which is the same direction of wrap of layer 12. This plurality of layers of helically wrapped ribbon 9 forms the spacing structure and insulation between the central conductor 6 and the shield conductor 4 as best shown in FIG. 2.

The formation of a helically wrapped layer of ribbon and the ribbon itself is shown in greater detail in FIG. 3. The ribbon in this embodiment is composed of continuous uniplanar film 20 and a plurality of parallel ribs 22 extending perpendicularly from one surface of the film and along the length of the ribbon. The ribbon is helically wrapped around the central conductor 6 as shown in FIG. 3 in such a way that the tops of the ribs 22 face inwardly. The

films of the turns 25 and 27 of the ribbon are in abutting relationship to produce a closed helix or continuous layer of ribbon. The helical wrapping of each of the layers 10, 12, 14 and 16 of FIG. 1 is slightly open to form discontinuous layers as will be explained hereinafter; however, this wrapping can be in the form of closed helices. The ribbon can be wrapped so that the ribs 22 face outwardly and the film faces inwardly. In another embodiment, the ribs 22 can extend from both surfaces of the film.

To return to the embodiment of FIG. 1, the plurality of layers of this helically wrapped ribbon presents an alternating sequence if ribs 22 and films 20 proceeding from the central conductor 6 to the shield conductor 4 as best shown in FIG. 2.

The ribs 22 space the films from the central conductor and from the film of the preceding layer to define spaces 24, which are in the form of a plurality of helical channels laterally defined by the ribs 22 of each ribbon. These spaces 24 are filled with a dielectric fluid (as may be desired for high voltage application) or with air. Preferred dielectric fluids are electronegative gases such as SF_6, under pressure such as of 2 atmospheres or higher, or fluorinated hydrocarbon bases, such as the "Freons" (trade mark) which may be used under pressure, depending on which gas is used.

The helical wrapping to form the layers 10, 12, 14 and 16 is done in such a way that the edges of the ribbon of a preceding layer are covered by film of the next layer. As shown in FIG. 2, the longitudinal edges of the film of each layer are not quite abutting one another, but instead are separated from each other to form small spaces 26. The helical wrapping of layers 10, 12, 14 and 16 is thus slightly open. The spaces 26, i.e., the helical turns of layer 10, are circumferentially offset from the spaces 26 or helical turns of the next layer 14 which has a helical wrap in the same direction of layer 10. The same circumferential offset is provided between the helical turns of the layers 12 and 16.

This offsetting of helical turns provides at least one film 20 at all points between the central conductor and the shield conductor 4. For a dielectric breakdown of the fluid or air to occur, the current path, instead of passing directly between the shield conductor and the central conductor, has the much longer path; namely, following a zig-zag course from space 26 to space 26 of the layers of ribbon in order for the current from one conductor to reach the other. This much longer path serves to increase the effective thickness used to calculate dielectric strength. Since dielectric strength does not change noticeably, the voltage at breakdown is increased, thereby permitting the cable to be used at higher voltages. For example, in a dielectric breakdown test, the breakdown for a free air gap of 0.6 cm between electrodes is 2.4 volts per micron. The use of five layers of ribbon in this same air gap, with the turns of each layer being in the same direction and 1/3 offset from one another, increases the stress required for breakdown to 7.2 volts per micron. The normally relatively high power loss associated with the use of high, relative to gas, dielectric constant, polymeric material is minimized by minimizing the amount of polymeric material that is used to make the ribbon.

In another embodiment of this invention, as shown in FIG. 4, film of dielectric material is laminated to the tops of the ribs 22 of the ribbon 9. This may be done in the case when the ribbon and other film are of dielectric thermoplastic polymeric material by heat-softening the tops of the ribs 22 with a heat source such as a burner 28 and immediately bringing into contact with the heat softened tops, the film 30 of thermoplastic polymeric material. This can be done on a continuous basis by moving the ribbon 9 and the film 30 in the direction indicated while maintaining their meeting point approximate to the burner 28. Pressure can be applied across the thickness of the resultant ribbon in order to strengthen the bond between the film 30 and the tops of the ribs 22 by passing the resultant laminate between the nip of a pair of oppositely rotating rolls spaced apart slightly less than the thickness of the laminate. In place of the burner 28, a freshly extruded film of dielectric thermoplastic polymeric material can be laminated to the tops of the ribs 22 by the application of pressure alone. The resultant laminate is used in substantially the same manner as the ribbon 9, with the additional film 30 providing increased transverse strength to the transmission line.

The laminate comprised of films 20 and 30 and ribs 22 can be used to form a single continuous layer of closed helical wrapping between the central conductor 6 and the shield conductor 4 as shown in FIG. 5. In this embodiment, the edges of the film are overlapped so as to present at least one solid surface of dielectric film at all points between the conductors 4 and 6. Instead of overlapping, the film edges can be abutting one another.

The laminate of FIG. 4 can also be used to form a plurality of layers of helical wrapping, such as layers 36 and 38 of FIG. 6, with the direction of wrap of these layers being reversed from one another in the same manner as layers 10 and 12 of FIG. 1. In another embodiment, the plurality of layers of helical wrapping of the ribbon 9 or

laminate of FIG. 4 may have the same direction of wrap, with the turns of each successive layer being off-set from the turns of the preceding layer in the same direction so as to prevent a straight-line path for electrical breakdown from occurring.

It is preferred that there is at least one continuous layer of film in the space between the central conductor and the shield conductor, with this film being spaced from each of these conductors. The embodiment of FIG. 6 provides this condition for the laminate of FIG. 4. The embodiment of FIG. 15 provides this condition when the ribbon 9 is used by itself.

The spaces 26 between helical turns of ribbon permit some sideways movement of the ribbon to thereby permit flexibility of the transmission line. The presence of this spacing between ribbon edges of the same layer is compensated for by the plurality of layers of ribbon which prevent a straight-line path between conductors 4 and 6 for breakdown of the dielectric fluid or air. If the film edges defining spaces 26 were abutting or overlapping the spaces would no longer be present, and the wrapping of FIG. 2 would be in the form of closed helices. One representative form of overlapping of films is as shown in FIG. 5. Alternatively, the overlapping edges can be complementarily beveled so as to provide a seam which is substantially the same thickness as the film. Another embodiment of abutting edges is to have these edges terminate in ribs, such as ribs 22 as shown in FIG. 15. This embodiment tends to prevent sideways movement of closed helically wrapped tape.

In still another embodiment of this invention, transverse notches 40 are provided in the ribs 22 as shown in FIG. 7. These notches are provided at the longitudinal spacing and to the depth desired and can terminate intermediate the surface of film 20 and the tops of the ribs 22 as depicted in the drawing. The resultant modified ribbon is used in the same manner as hereinbefore described with respect to the ribbon embodiments of FIGS. 3 and 4.

The helical channels laterally defined by the ribs 22 of the ribbon can be connected to a pump (not shown) which can be used to continuously flow dielectric fluid along the transmission line, thus providing cooling as well as insulation. Any moisture which may enter the transmission line would also be removed by providing a source for drying the fluid in the pumping circuit. The ribbon embodiment of FIG. 7 is particularly useful in this aspect by providing communication between the various channels, in case one or more of the channels are blocked.

Instead of helical wrapping, the ribbon can be wrapped around the inner or central conductor in cigarette paper wrap fashion as illustrated in FIG. 12 wherein ribbon 50, which is similar to ribbon 9, is progressively wrapped around the central conductor 6 so as to form a seam 52 of the longitudinal edges of the ribbon joined together, the seam extending parallel to the axis of the conductor. The ribs 54 of the ribbon 50 also extend parallel to the axis of the conductor and are directed inwardly against the surface of the conductor as shown in FIG. 13. The seam 52 can be in the form of complementarily beveled abutting edges 56 shown in FIG. 13 or other form of abutment or overlap such as shown in FIGS. 5 and 15 to form a continuous layer of wrapping. The edges can be joined together to form the seam 52 by such means as adhesive or heat bonding. The ribbon can be applied continuously to the conductor 6 by moving both in the same direction and at the same speed and by applying localized heating to the edges of the ribbon 50 just prior to coming together into seam 52. The heating is sufficient to melt the portions of the edges which come into contact with one another, whereby upon such contact and subsequent cooling, the heat bond is formed. These techniques can also be applied to join the edges of ribbon wrapped in a closed helix. The wrapping in cigarette paper wrap fashion can be done with stationary conductor 6 and ribbon 50.

Either the central conductor 6 or the tops of the ribs 54 can be coated with an adhesive or otherwise treated to adhere together, if desired, in order to aid in stabilizing the ribs 54 against the central conductor. Alternatively, the embodiment of ribbon shown formed in FIG. 4 can be used. The ribbon 50 can be notched similar to the manner shown in FIG. 7, if desired, for the purpose of providing communication between the channels formed between the film 58 and conductor 6, should blockage occur.

A plurality of layers of ribbon wrapped in cigarette paper wrap fashion can be used, with the longitudinal seam of one layer either coinciding with or being offset from an adjacent layer. When more than one layer of ribbon is used to form a transmission line of this invention, one or more layers can be formed by cigarette paper wrap and the remainder by helical wrap. For example, the layer adjacent the central conductor 6 can be ribbon 50 in cigarette paper wrap fashion and the layer adjacent the shield conductor 4 can be ribbon 60, similar to ribbon 9, in helical wrap fashion, as shown in FIG. 14. An opposite combination of wrapping style can be used, or variations thereon wherein one or more layers of one style of wrapping are sandwiched between or alternated with layers of the other style of wrapping which can be used.

The number of layers of helical wrapping

of ribbon used in the present invention will depend primarily on the total insulation thickness required for a specific voltage stress design and the particular ribbon employed.

Use of multiple layers of ribbon according to the present invention has led to the discovery of a surprising phenomenon. Ordinarily, when a solid dielectric barrier is introduced between spaced electrodes of opposite polarity, the operating voltage of the line containing the electrodes is reduced. This reduction may not be detrimental in using the line for low voltage applications, such as for communications, but is detrimental when the line is operated at high voltages for power purposes. Dielectric breakdown is generally preceded by corona discharge from one of the electrodes. The voltage at which this discharge is first detected is called the corona inception voltage (CIV). Instead of following the trend of reduced corona inception voltage obtained for the introduction of a single solid dielectric barrier between electrodes, the presence of multiple dielectric barriers dividing the gap at all points radially between the inner conductor and the outer coating into at least three spaces concentrically arranged increases the CIV and thereby the maximum operating voltage of the line. The dielectric barrier is provided by the film of the ribbon, and the ribs extending from the surface of the film space the film of one layer of ribbon from the film of the ribbon of an adjacent layer. The number of layers of ribbon wrapped around the inner conductor required to obtain the minimum of three spaces will depend on the manner in which the ribbon is wrapped. When the wrapping is in continuous layers, three such layers are sufficient (provides two layers of film spaced from each other and for each electrode). For example, as few as three continuous layers of ribbon (1.27 mm. thick composed of 0.10 mm. thick film having ribs 0.32 cm. apart, 0.25 mm. wide and 1.17 mm. high) increase the corona inception voltage over a free air gap at atmospheric pressure by about 7%. As the number of layers increases so does the corona inception voltage. For six continuous layers of the same ribbon, the increase in corona inception voltage is about 25%. Wrapping in discontinuous layers, such as open helical wrapping in offset layers, is somewhat less effective depending on such factors as degree of openness of the wrap, the degree of offset of succeeding layers, and the direction of wrap of the layers relative to each other. Generally, at least four to six such layers is required to provide at least two layers of film spaced from each other and from each conductor at all points between the conductors. By way of example, the embodiment of FIG. 2 provides the minimum of three spaces in the gap between the conductors. To obtain the maximum benefit in increased operating voltage, resulting from increased path length for breakdown and increased CIV, it is preferred that if helical wrapping is used, whether open or closed, the direction of wrap in each successive layer be in the same direction, with the turns in each successive layer being about 1/3 to 1/2 (width of the ribbon) offset from one another. This construction can be strengthened by an outer layer and/or one or more intermediate layers of helical wrapping in the opposite direction.

While the embodiments of the drawings discussed up to this point are coaxial cable, the present invention is not limited to such cable; the principles and features discussed are equally applicable to transmission lines, such as disclosed hereinbefore, in which the inner conductor is displaced from the axis of the outer coating, whether it be a shield conductor or an insulator. For example, as shown in FIG. 20, each inner conductor 64 of a sector power cable is wrapped in two layers 66 and 68 of ribbon of any type disclosed herein in a closed helical fashion, with the turns of the helices being in the same direction and offset from inner layer to outer layer. The three wrapped inner conductors 64 are encased in a single shield conductor 70. By way of another example, as shown in FIG. 21, each inner conductor 72 of a balanced twin lead communications cable is wrapped in a single layer 74 of ribbon of any type disclosed herein in cigarette paper wrap fashion and encased together in a single insulation jacket 76 of polymeric material.

A still further aspect of the present invention is the use of the ribbon disclosed hereinbefore to replace the multiple layers of helically wound tape used in the "Styroflex (trade mark) cable construction. As shown in FIG. 22, this type of construction generally comprises central conductor 78 coaxially spaced from a shield conductor 80 by an open helical wrapping 82 which normally consists of coextensive layers of tape. According to the present invention, this tape is replaced by ribbon, such as ribbon 9, whereby the wrapping 82 consists of multiple layers 84 of such ribbon; for example, seven coextensive layers as shown for the cut-away portion of the wrapping 82 in FIG. 22. For simplicity, a layer of reversed open-helically wrapped tape which may be sandwiched between the outer layer of wrapping 82 and conductor 80 has been omitted; but this, too, can be replaced by the ribbon disclosed herein. The layers 84 of ribbon can be laminated to one another by such methods as heat bonding or using adhesive between layers. The open helix

of the "Styroflex" construction differs from the open helix of the wrapping of layers 10, 12, 14 and 16 of FIG. 2 by not having at least one layer of film present at all points between the conductors of the cable.

With respect to the other components of transmission lines constructed according to the present invention, the inner conductor can vary in cross-sectional shape from the circular shape, and can be hollow and/or of stranded wires instead of solid, and the ribbon will still generally conform to the surface of the conductor. The inner conductor can also be made of a plurality of wires encased in a wrapping or coating of semi-conductive material, such as polyethylene filled with carbon black, in order to even out the electrical field surrounding the central conductor. The outer coating can be in such forms as a solid tubing of annular cross-section or tubing formed by wrapping conductive material helically or otherwise around the outer layer of ribbon. The outer coating can also be corrugated to aid in the flexibility of the transmission line. The outer coating may contain a layer of semi-conductor material. Another form of outer coating is that which is composed of a layer of semi-conductor material having conductor wires positioned on the outer surface thereof whether in a plurality of straight paths or helical paths. The conductive material for use as both the shield conductor and central conductor will be the conventional conductor materials, most commonly copper. A shield conductor will generally be jacketed in an insulating material (not shown), such as polyethylene, in sufficient thickness, e.g., 0.6 cm. to, as much as possible, exclude moisture from laterally entering the transmission line, and to retain the dielectric fluid therein should it be a gas.

The transmission line of this invention can be made by standard manufacturing techniques such as related to wrapping and extrusion jacketing. The resultant transmission line is sufficiently strong in transverse strength to be capable of withstanding reeling and reasonable handling without disturbing the disposition of the conductors.

The ribbon for use in wrapping either in helical or cigarette paper wrap fashion in accordance with this invention can be made by standard extrusion techniques employing an extrusion die opening having approximately the shape of the cross-section desired for the ribbon. The number and depth of the ribs and the film thickness can be varied as desired within machine capability limits (and within the bulk density limitation described above).

A preferred method and apparatus for making the ribbon is described hereinafter with reference to FIGS. 8 to 11. (A method and apparatus for making a preferred ribbon is also described and claimed in our co-opending Application No. 23836/67 (Serial No. 1,174,287).) In FIG. 8 is shown an extruder 100 equipped with a hopper 102 for receiving thermoplastic resin and melting it under pressure. A die 104 receives the pressurized molten resin through its rear (hidden) side from the extruder and passes the resin along a path 106 which terminates in an outlet in pressure-seal relation with a rotating patterned roll 108 and directs the resin substantially free of pressure drop and in the absence of air into the pattern of the roll. The roll 108 continuously moves the molten resin away from the outlet of path 106, thereby forming a continuous molded web 110 having a pattern which is complementary to that of the roll. The web 110 is chilled by a flume or water spray 112, and after sufficient contact with the roll 108 which is internally cooled, the cooled web is removed from the roll by take-off rolls 114 aided by a stripper roll 116 and, optionally, mold release agent applied by spray nozzles 118 to the surface of the roll prior to passage under die 104. Longitudinal dividing or trimming of web 110 is accomplished, if desired, by one or more blades 120 positioned between the take-off rolls 114 and one or more reels 121 (only one shown).

To further describe the die 104 and patterned roll 108, which comprise the molding apparatus, FIG. 9 shows one embodiment in which die 104 contains a cavity 124 serving as path 106 (FIG. 8) and which is supplied with molten thermoplastic resin 126 through inlet pipe 127 by extruder 100. Die 104 is heated to a temperature above the resin melting temperature of the particular resin being used, by electrical heating elements 140 extending into corresponding wells in the die. The resin melting temperature is the minimum temperature at which a fresh sample of resin leaves a molten train as it is moved slowly across a heated metal surface. This is also sometimes called the stick temperature. Cavity 124 terminates in a slot-shaped outlet 128 extending across the surface of roll 108. The rearward and forward edges of outlet 128 are defined by a die plate 130 and a doctor blade 132, each adjustably spaced from roll 108 and secured to die 104 by bolts 134 extending through slots 136. The pressure upon the molten resin 126 in the cavity forces the resin through outlet 128 and into the roll pattern represented by circumferential grooves 138 (only one shown). The cavity 124 and outlet 128 are substantially free of constriction so that the pressure on the resin at the surface of roll 108 is substan-

tially the same as the pressure on the resin in cavity 124.

The grooves 138 mold the ribs extending from one surface of the web 110. The opposite surface of the web is formed by doctor blade 132 which is adjustably spaced from roll 108 to give the web thickness desired. The web 110 is thus in the form of ribbon such as shown in FIG. 3, with the longitudinal dividing by blades 120 giving the ribbon width desired. The doctor blade 132 can be notched to form ribs on the opposite surface of the web.

In further detail doctor blade 132 is heated by an electrical heating element 141 usually to a temperature which is equal to or greater than the temperature maintained by die 104. The outer face 143 of the doctor blade departs sharply from the path of web 110 so as to avoid sticking of the web to the hot doctor blade. Roll 108 is cooled to a temperature which is at least 10°C. less than the melting temperature of the resin being molded, such as by passing a cooling medium through an interior passage 109.

In FIG. 10 essentially the same equipment arrangement as in FIG. 9 is used except that slot-shaped outlet 128 includes a wedge-shaped passage 200 extending in the direction of rotation of roll 108. The wedge-shape of the passage 200 is formed by doctor blade 132 having a slant surface 202 facing the roll 108. Movement of the surface of roll 108 past the opening 128 drags molten resin into the passage 200 wherein the flowing resin is forced into the pattern of roll 108. This drag flow pressure created in the passage 200 at the surface of the roll augments the pressure on the resin within cavity 124 of the die.

The wedge-shaped passage 200 can be of any configuration which augments the molding pressure supplied by the extruder. Generally, the passage 200 will take the form of converging surfaces, with the roll pattern forming one of these surfaces. The pressures required on molten thermoplastic resin in cavity 124 can be less than the full extrusion pressure of the extruder, depending upon which resin is employed and upon operating conditions. The pressure in the cavity 124, however, is substantially the same as the pressure on the resin coming into contact with the pattern of the roll surface. When such pressure is insufficient, the drag flow arrangement of FIG. 10 can be used to increase the force present for continuously filling the pattern with molten resin.

The molding apparatus of FIGS. 9 and 10 can be provided with water spray 112 and mold release spray nozzles 118 as shown in FIG. 8.

A pressure-seal relation between the outlet 128 for the molten thermoplastic resin and roll 108 is maintained so that the pressure on the resin in cavity 124 and the drag flow pressure, when the apparatus of FIG. 10 is employed, are available to force the resin into the pattern of roll 108 on a continuous and high speed of production basis. The pressure-seal relation is obtained, in part, by adjusting the doctor blade 132 to constrict the flow space for the resin as it leaves outlet 128 and by having a sufficient rate of web formation for the viscosity of the particular resin being molded to prevent back flow under the die plate 130 which is generally spaced 2 to 10 mils from the surface of roll 108.

FIG. 11 shows, in indeterminate width, means for laterally confining the molten thermoplastic resin as it leaves opening 128 so as to complete the pressure-seal relation. In FIG. 11, the doctor blade 132 is shown in operative position and provided with heating element 141. The lateral surface of the roll 108 is provided with a pattern, shown in enlargement, of circumferential grooves 138 terminating at shoulders 160 formed between the surface of the roll and cylindrical ends 162 of reduced diameter extending from each end of the roll. The molten resin from cavity 124 is molded into a web which extends entirely across the roll pattern. Further sideways flow of the resin, however, is prevented by a pair of end plates 166 adjustably spaced from roll 108 by bolts 168 passing through slots (not shown) in the end plates and tightened into die 104. The end plates 166 each lie close to the shoulders 160 and have a lower arcuate surface lying close to the corresponding surface of cylindrical ends 162. This close spacing, on the order of about 50 microns, permits a small amount of molten resin to enter the tortuous path around shoulders 160 before chilling of the resin occurs. This chilling prevents sideways leakage of additional resin and loss of molding pressure. A low friction pressure sealing system, without the need for metal-to-metal contact or necessity for further lubrication, is provided by this small amount of resin entering between end plates 166 and roll 108. The end plates 166 also form the lateral sides for cavity 124 and the die outlet 128 which is coextensive therewith.

Means can also be provided for changing the spacing between the die 104 and the roll 108 to compensate for pressure fluctuations caused by extruder 100 so as to maintain a constant force on the resin entering the roll pattern. Exemplary of such means is the pivotal mounting of die 104 about a stub shaft 170 which is on center with the feed line between extruder 100 and the die, and providing a lever arm 172 having the desired weight 174 suspended therefrom as shown in FIG. 8. Excessive molding pres-

sure is relieved by the die 104 rotating away from roll 108. Upon return of the pressure to normal, weight 174 restores the die 104 to its former position to produce web of the desired thickness.

While in all the foregoing disclosed embodiments, the ribs run parallel to the length of the ribbon, the present invention is not limited to the use of such ribbon. Suitable ribbon can be made by the foregoing described apparatus, in which the ribs are inclined from or perpendicular to the length of the ribbon, or form connected or disconnected patterns of polygonal shapes, such as rectanglues, triangles or hexagons, or curvilinear shapes such as circles, by having corresponding grooves in the surface of the roll 108. FIGS. 16 and 17 show a ribbon 86 helically wrapped around an inner conductor 87, with the ribbon consisting of a film 88 and ribs 89 extending therefrom at an angle of about 80° with the length direction of the film. In this embodiment, the angle which the ribs make with the length direction of the ribbon is chosen so that the ribs run substantially parallel to the inner conductor 87 when the ribbon is helically wrapped therearound. The particular angle chosen to give this result will depend primarily on the diameter of the inner conductor and the helix angle of the wrap. Instead of helical channels, these ribs 89 form channels which extend substantially parallel to the axis of the inner conductor, with the channels being somewhat irregular from turn to turn in each layer of helical wrapping if the ribs thereof fail to line up. The path of air or dielectric fluid along the length of the cable is considerably shortened by this embodiment. FIGS. 18 and 19 show another embodiment of ribbon, namely ribbon 92 consisting of film 93, and a network of ribs 94 and 95 running parallel and perpendicular, respectively, to the length of the ribbon, helically wrapped around inner conductor 96. This embodiment of ribbon is useful when air or dielectric fluid flow is not required. These embodiments of ribbon can be used in different styles of wrapping and can be modified along the lines of FIG. 4 and/or FIG. 5. When a film 30 (FIG. 4) is laminated to the tops of ribs in a connected or network pattern, closed cells are formed between the film 30 and film of the ribbon.

Details illustrating the manufacture of ribbon for use in accordance with the present invention are as follows: The patterned roll has a 15.2 cm. wide pattern in its surface consisting of grooves 0.25 mm. wide by 1.27 mm. deep and spaced about 3.2 mm. apart running parallel to the direction of rotation of the roll. The roll is maintained at a temperature of about 80°C. and is rotated at a surface speed of about 6.1 metres/min. Linear polyethylene is forced at 275°C. and at a pressure of about 18 atm. into the pattern of the roll from a pivotally mounted die having its outlet 128 and doctor blade 132 maintained about 0.10 mm. from the roll during operation by a weight acting through a 76 cm. lever arm. No mold release agent is used. The resultant web or ribbon consists of continuous film measuring about 0.10 mm. in thickness and having integrally molded parallel ribs spaced 3.2 mm. from each other, the ribs measuring 0.25 mm. wide by 1.27 mm. deep.

A ribbon is made in the same equipment but from polyhexamethylene adipamide (66 nylon) instead of polyethylene, by operating the patterned roll at 150°C. and a molding temperature of 270°C. and pressure of 7.8 atm.

The same equipment is used to make a ribbon from a copolymer of tetrafluoroethylene and hexafluoropropylene by operating the patterned roll at 190°C. and a molding temperature of 320°C. The copolymer is described in Example V of U.C. Patent No. 3,085,083 to Schreyer (15% by wt. of hexafluoropropylene) containing about 88% $-CF_2H$ end groups and having a specific melt viscosity of about 9 x 10^4 poises at 380°C. The monomers are copolymerized in accordance with the procedure of Example I of U.S. Patent No. 2,946,763 to Bro et al.

A laminate is made from the polyethylene ribbon formed as just described by extruding a 0.10 mm. polyethylene film from a film die at 275°C. onto a chill roll operating at 88°C. and forming a 1.42 mm. nip with another roll and simultaneously passing the film and web, rib-side towards the film through the nip to thereby force the film against the tops of the ribs to form a laminate containing a core of parallel ribs.

A length of coaxial transmission line is made using a 2.54 cm. wide ribbon of the polyethylene laminate just described. The ribbon is helically wrapped with abutting turns around a central conductor (1.27 cm. in diameter) in seven layers, with the direction of wrap of each successive layer being reversed and with the turns of the layers being off-set from one another to prevent a straight-through path for dielectric breakdown. Each succeeding layer holds the previous layer in place. Aluminum foil is helically wrapped around the outermost layer of ribbon to serve as the shield conductor. The ends of this foil are held in place by taping. The dielectric constant and dissipation factor of the insulation structure (seven layers of ribbon containing air in the spaces between the ribs), as measured according to ASTM D 150-65T, are 1.4 and 0.00003, respectively. When the same trans-

mission line is made, except that the direction of helical wrap of each layer is in the same direction and the turns of the layers are 1/3 offset from one another, the line has a higher breakdown voltage.

A polyethylene ribbon 1.66 cm. wide and consisting of a continuous film 0.10 mm. thick and integrally molded parallel ribs 1.83 mm. apart, 0.25 mm. wide, and 1.27 mm. deep is used to form a single layer of cigarette paper wrap around a central conductor 2.5 mm. in diameter. The edges of the ribbon come together forming a butt joint and are heat bonded together. A helical wrapping of aluminum foil around the layer of ribbon is used to form the shield conductor.

Generally, the ribs of the ribbon are uniformly spaced as far apart as possible to obtain low bulk densities yet while providing sufficient transverse strength. The strength requirement will be dictated by the wrapping style to be employed, i.e., helical or cigarette paper wrap, as well as by the number of layers of wrapping and the particular inner conductor and outer coating employed. The bulk density of the rib stratum of the ribbon can be less than 20% and preferably less than 12% of the density of the polymeric material from which the ribbon is made. Preferably, the bulk density of the ribbon is less than 20% of the density of the polymeric material from which it is made. Representative dimensions for ribbons which can be made by the process described hereinbefore are as follows, all dimensions being in centimeters:

WIDTH OF RIBS	HEIGHT OF RIBS	SPACING BETWEEN RIBS	FILM THICKNESS
0.010	0.064	0.186	0.0043
0.013	0.097	0.272	0.0064
0.015	0.142	0.381	0.0089
0.018	0.183	0.432	0.0102
0.025	0.127	0.356	0.0203
0.030	0.254	0.316	0.0190

The dielectric polymeric materials which are useful in making ribbon for use in the present invention are generally those which can be formed into the ribbon shape by such processes as extruding, molding or casting. As to electrical character, the polymeric material should have a dielectric constant of less than 10 and preferably less than 5.5, and a dissipation factor (energy loss) of no greater than 0.01, and preferably no greater than 0.001.

Suitable polymeric materials include: polyurethanes, natural and synthetic rubbers such as polychloroprenes, EPT (ethylene-propylene terpolymer) sulfur-curable elastomers such as described in U.S. Patent No. 2,933,480, and copolymers of hexafluoropropylene with vinylidene fluoride and optionally tetrafluoroethylene; thermoplastic resins, including polystyrene, high impact polystyrene, ABS resin, the saturated hydrocarbon polymers, such as polyethylene, linear or branched, polypropylene and copolymers thereof; ionomers such as described in Canadian Patents 674,595 and 713,631, both to R. W. Rees; copolymers of ethylene with an α,β-unsaturated carboxylic acid such as described in British Patent 963,380 to Du Pont, and blends thereof with saturated hydrocarbon polymers and such blends containing co-crystallized oxide water activated cross-linking agents such as described in British Patent No. 998,439, granted November 3, 1965, to Halliwell et al.; halogenated or perhalogenated olefin polymers, such as polymers of vinyl chloride, vinylidene chloride, chlorotrifluoroethylene, vinyl fluoride and vinylidene fluoride and melt fabricable tetrafluoroethylene polymers, including such co-monomers as hexafluoropropylene, perfluoroalkyl vinyl ether, e.g., perfluoropropyl vinyl ether or the monomer described and claimed in U.S. Patent No. 3,308,107 to Selman and Squire; polyvinyl acetate and copolymers thereof with saturated hydrocarbon polymers and optionally, the acid copolymers of British Patent 963,380 to Du Pont; polymers of α,β-unsaturated carboxylic acid, such as polymethyl-methacrylate; the polyamides such as polyhexamethylene adipamide (66 nylon), polyhexamethylene sebacamide (610 nylon), polycaprolactam (6 nylon), copolymers, ionomers and/or saturated hydrocarbon polymers; polyoxymethylene polymer and copolymer; polycarbonate; polysulfone; and polyethylene terephthalate. These polymeric materials can contain any of the various additives used to modify the resin, such as antioxidants, fillers, reinforcing agents, such as fiber glass, hydrolytic and thermal stabilizers and colorants, so long as the electrical requirements herein set forth are met.

The particular molding temperatures employed in making ribbon will depend upon such operating conditions as the speed of the patterned roll 108 and the intricacy of the pattern therein. Typical molding temperatures for some of the suitable resins are as follows: linear polyethylene 200-250°C.; branched polyethylene 180-190°C.; polypropylene 200-250°C.; polystyrene 240-280°C.; polyvinyl chloride 150-170°C.; and 66 nylon 260-350°C.

The present invention provides several advantages over the art. Though the ribbon employed in this invention as the dielectric spacer material in power cables is applied by ordinary and convenient manufacturing techniques, such power cables exhibit the advantages of both the solid and fluid dielectric materials of the art, without the detriments inherent therein. Moreover, power

cables according to this invention possess mechanical strength in the transverse direction.

WHAT WE CLAIM IS:—

1. A line for transmitting electrical energy, which comprises (1) an outer protective coating which is either a shield conductor or an insulator, (2) at least one inner conductor, and (3) a dielectric insulating spacer structure which positions the inner conductors within the outer protective coating and insulates the inner conductors from one another when more than one inner conductor is present, the spacer structure comprising at least one layer of ribbon wrapped around the or each inner conductor, the ribbon being formed from a dielectric polymeric material and comprising a continuous film and a plurality of ribs extending from at least one surface of the film, the bulk density of the ribbon being less than 30% of the density of the polymeric material from which it is formed.

2. A transmission line according to claim 1 wherein the ribbon is wrapped helically around the or each inner conductor, the ribs of the ribbon extending along the longitudinal direction of the ribbon.

3. A transmission line according to claim 2 wherein the ribbon is wrapped in closed helical fashion around the inner conductor.

4. A transmission line according to claim 3 wherein the edges of the ribbon in successive turns overlap one another.

5. A transmission line according to any of claims 2 to 4 wherein the spacer structure comprises at least two layers of the ribbon, successive layers of ribbon being helically wrapped in opposite directions.

6. A transmission line according to any of claims 2 to 4 wherein the spacer structure comprises at least two layers of the ribbon helically wrapped in the same direction, the turns of each layer being offset from the turns of the adjacent layers.

7. A transmission line according to claim 1 wherein the ribbon is wrapped around the or each inner conductor in cigarette paper wrap fashion.

8. A transmission line according to claim 7 wherein the abutting edges of the ribbon are heat bonded together.

9. A transmission line according to claim 7 or 8 wherein the tops of the ribs are adhered to the surface of the inner conductor(s).

10. A transmission line according to claim 1 wherein the spacer structure comprises at least two layers of the ribbon, at least one of the layers of ribbon being helically wrapped and at least one of the layers of ribbon being wrapped in cigarette paper wrap fashion.

11. A transmission line according to claim 1 wherein the ribs extend transverse as to divide the gap between the or each inner conductor and the outer conductor into at least three concentric spaces.

12. A transmission line according to claim 1 wheredin the ribs extend transverse to the length direction of the ribbon and the wrapping of the ribbon around the or each inner conductor is helical.

13. A transmission line according to claim 12 wherein the ribs extend substantially parallel to the axis of the inner conductor.

14. A transmission line according to claim 1 wherein a plurality of layers of the ribbon are wrapped around the or each inner conductor, each layer being in the form of an open helix and the layers being coextensive with one another.

15. A transmission line according to any of claims 1 to 14 wherein a continuous film is laminated to the tops of the ribs of the ribbon.

16. A transmission line according to any of claims 1 to 15 wherein the ribs of the ribbon are transversely grooved to provide communication between the spaces on either side of the ribs.

17. A transmission line according to any of claims 1 to 16 wherein the polymeric material is polyethylene or a copolymer of tetrafluoroethylene and hexafluoropropylene.

18. A transmission line according to claim 1 substantially as herein described with reference to any of Figures 1, 2, 3, 5, 6 and 12 to 22.

A. A. THORNTON & CO.,
Chartered Patent Agents,
Northumberland House,
303/306 High Holborn,
London, W.C.1.

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1174288 COMPLETE SPECIFICATION

5 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig. 1.

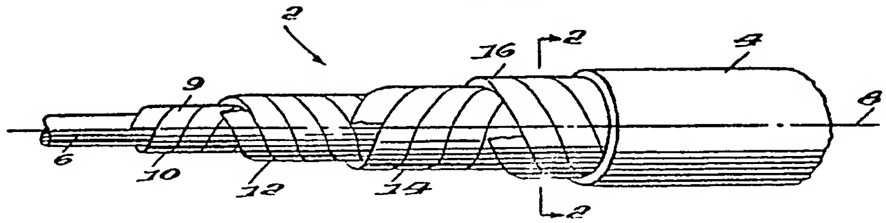


Fig. 2.

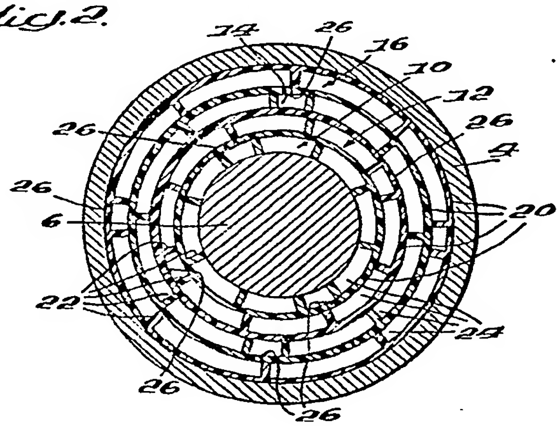
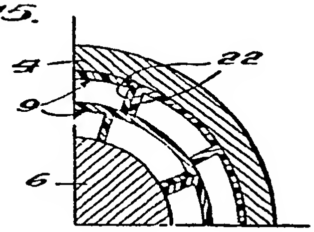


Fig. 15.



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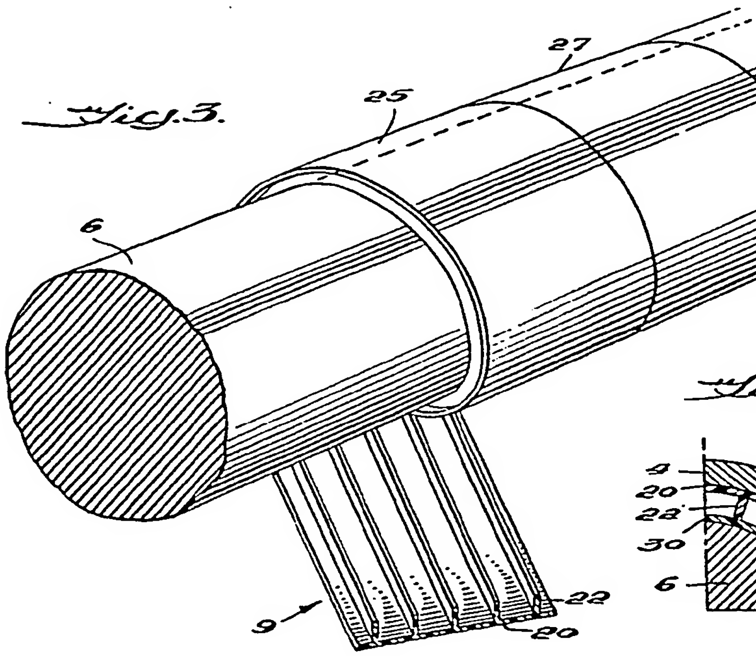

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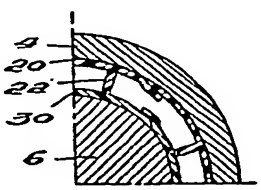

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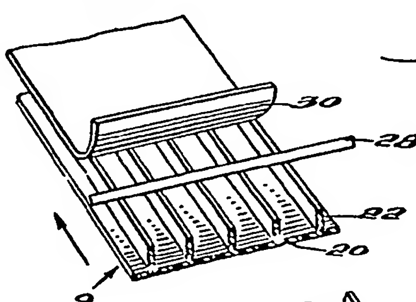

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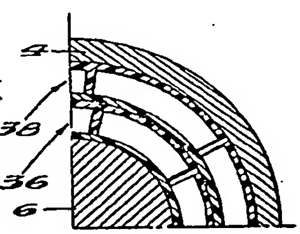

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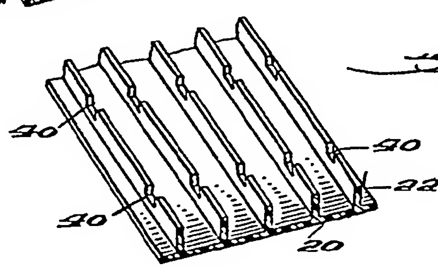

1174288 COMPLETE SPECIFICATION

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Sheet 3

Fig. 8.

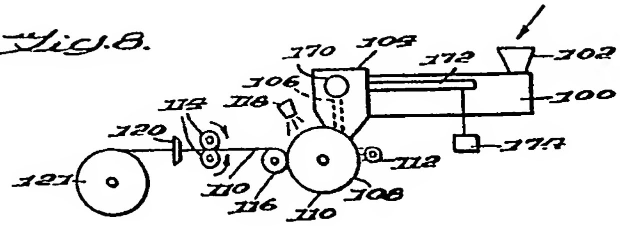

Fig. 9.

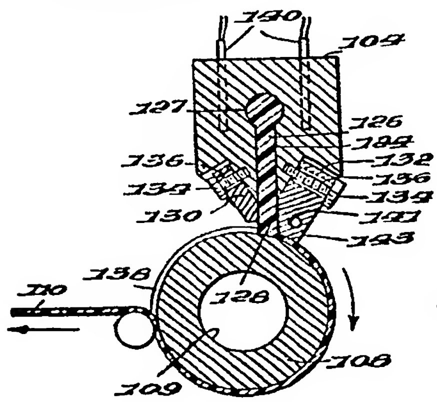

Fig. 10

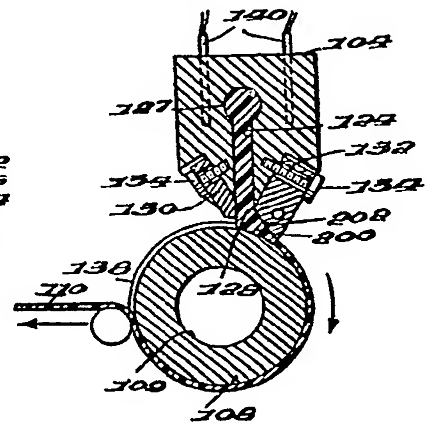

Fig. 11.

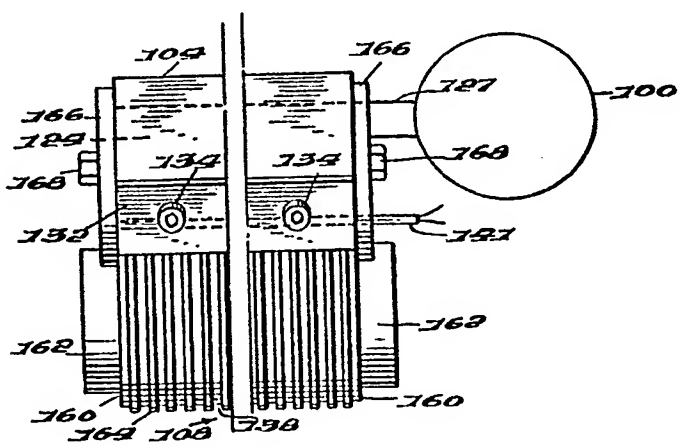

Fig. 12.

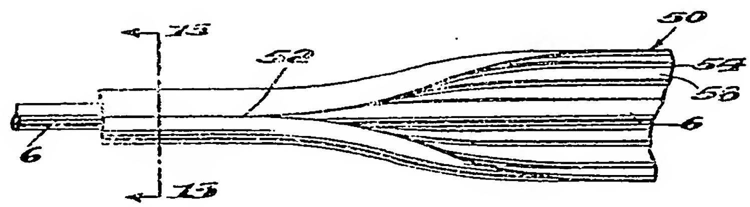

Fig. 13.

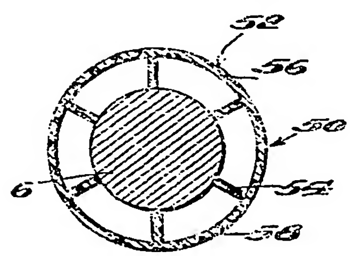

Fig. 14.

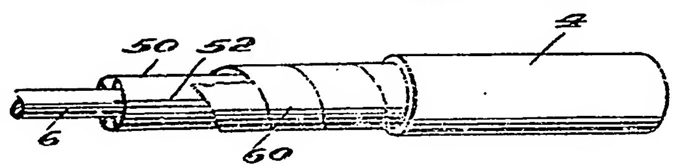

Fig. 16.

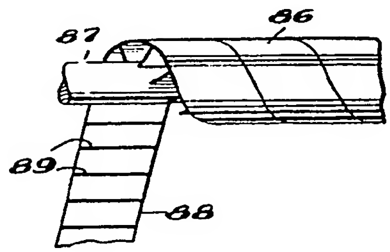

Fig. 17.

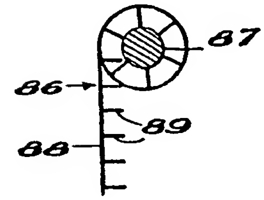

Fig. 18.

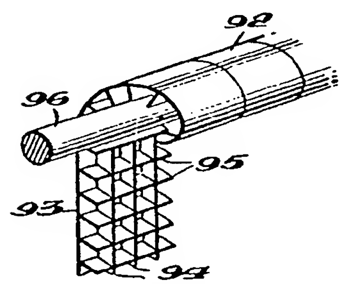

Fig. 19.

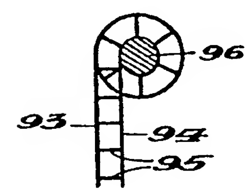

Fig. 20.

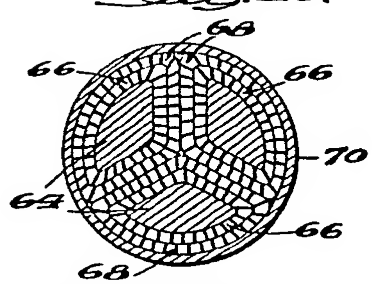

Fig. 21.

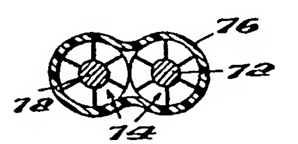

Fig. 22.